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Terrestrial Magnetism	Aurora and Night Airglow
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[illegible]

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[illegible]

in which the a's are constants, were used in these calculations. The first function, $M(N)$

The Influence of Modulation Effects on Solar Flare Radiation*

By Robert R. BROWN

Department of Physics, University of California

(Read October 26, 1958; Received November 22, 1958)

Abstract

The modulation of cosmic rays at the time of the February 23, 1956 solar flare cosmic ray outburst has been estimated from the latitude variation of the cosmic ray intensity decrease observed in the period surrounding the flare event. The perturbing influence of these modulation effects on the rigidity spectrum of the flare radiation has been calculated. The change in the slope of the rigidity spectrum is found to be small as the modulation function does not have a strong dependence on rigidity between low and middle magnetic latitudes.

Introduction

The continuous recording of cosmic ray intensity variations over the past twenty years has shown that on five occasions (Singer, 1957) solar particles have been injected into the cosmic ray beam following large flare outbursts on the sun. The most recent solar flare event (Elliot and Gold, 1956) which occurred on February 23, 1956 was unusual in two respects: first, it gave the largest intensity increase of the five events, with effects extending even to equatorial latitudes and second, it occurred during a large intensity decrease resulting from an intense outburst of solar activity. These cosmic ray time variations were recorded by such a large number of meson and neutron monitors, distributed over a wide range in latitudes, that it has been possible to study both the properties of the solar-produced radiation and the modulation of cosmic ray particles of non-solar origin in greater detail than ever before.

Observations of the solar flare radiation show that the intensity increase at the earth set in less than an hour after the flare but decayed away much more slowly, the cosmic ray intensity remaining above the pre-flare value for many hours. Analyses of the latitude variation of the flare increase indicate that the rigidity spectrum of the flare radiation was much steeper than that of normal cosmic radiation. Thus, Meyer, Parker and Simpson (1956), Pfotzer (1956) and Kawabata, Kondo, Murakami and Wada (1957) find that the differential rigidity spectrum of the radiation may be represented by a power law with exponent γ between -6 and -7, depending on the time of observation.

Several models (Meyer P. et al., 1956; Kawabata et al., 1957; Brown, 1957) of the electromagnetic conditions in interplanetary space at the time of the flare increase have

* Supported in part by the joint program of the U.S. Office of Naval Research and the U.S. Atomic Energy Commission.

been proposed to explain the observed time variations of the flare radiation. These models are constructed around field configurations which ensure the rapid onset of direct flare radiation at the earth and yet provide means for the storage of indirect flare radiation in the solar system for many hours. However, the observed superposition of a flare increase and an intensity decrease imposes an additional limitation on the electromagnetic conditions in interplanetary space at the time of the flare; in particular, those features of the field configuration responsible for modulation effects must not interfere seriously with the propagation of flare radiation. As a result of this limitation, it has been suggested by Parker (1956) that the solar-induced modulation effects arise from electromagnetic conditions fairly close to the earth. While such local conditions would not perturb seriously the main features of solar flare time variations, they would influence the rigidity spectrum of the flare radiation. Thus, since flare particles coming from the vicinity of the sun must penetrate regions where modulation effects arise before reaching the earth, the rigidity spectrum of the flare radiation would be steepened somewhat by these local fields.

In the present paper an attempt is made to evaluate quantitatively the influence of modulation effects on the rigidity spectrum of flare radiation. In order to do this, the degree of modulation at the time of the flare has been estimated from the latitude variation of the cosmic ray intensity decrease in the interval surrounding the flare event. With the aid of the modulation function obtained from this analysis, an upper limit on the change in the rigidity spectrum exponent has been obtained.

Calculations

The degree of modulation present at the time of the flare was estimated from the latitude variation of the intensity decrease which reached its minimum value two days prior to the flare. Thus, the modulation function $M(N)$ was obtained by inserting trial functions in

$$\left[\frac{\delta I(\lambda)}{I(\lambda)}\right]=\frac{\sum_z\int_{N_c(\lambda)}^{\infty}\left\{M(N)-1\right\}j_z(N)S_z(N)dN}{\sum_z\int_{N_c(\lambda)}^{\infty}j_z(N)S_z(N)dN}$$

where $j_z(N)$ is the differential rigidity spectrum of primary cosmic ray particles of charge z, $S_z(N)$ is the yield function for these particles and $N_c(\lambda)$ is the cut-off rigidity at geomagnetic latitude λ, and comparing the calculated latitude variation with experimental observations. Trial functions of the form

$$M_1(N)=\frac{N^2}{N^2+K_1},$$

$$M_2(N)=\frac{N^{3/2}}{N^{3/2}+K_2}$$

and

$$M_3(N)=\frac{N}{N+K_3}$$

where the $K's$ are constants, were used in these calculations. The first function, $M_1(N)$

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variation of cosmic ray intensity than a system based on the shifted equator. This follows from examination of the latitude variation of the nucleonic component at sea-level (Rose, Fenton, Katzman and Simpson, 1956) expressed in terms of both the con-

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rigidity. In view of this, it would seem that conventional geomagnetic coordinates are more appropriate to the problem, at least until more definitive information on

is the type proposed in the geocentric nebula model (Parker, 1956); the other function, $M_2(N)$ and $M_3(N)$, were introduced to determine the modulation effects of functions with less of a rigidity dependence.

The primary spectra used in the calculations were those due to Kaplon *et al* (1952) while the yield function was that developed by Fonger (1953) and the cut-off rigidities were calculated from conventional geomagnetic theory. In this connection, it should be noted that there is some question at the present time as to the correct coordinate system for cosmic ray calculations. This results from the observations of Simpson *et al* (1956) that the cosmic ray equator is shifted westward from the position of the equator in conventional geomagnetic coordinates. This question cannot be resolved until a more complete survey of cosmic ray coordinates has been undertaken. However, the conventional coordinate system gives a more consistent description of the latitude variation of cosmic ray intensity than a system based on the shifted equator. This follows from examination of the latitude variation of the nucleonic component at sea-level (Rose, Fenton, Katzmann and Simpson, 1956) expressed in terms of both the conventional and shifted coordinates; this shows that when the shifted coordinate system is extrapolated to middle and high latitudes, the cosmic ray intensity no longer depends uniquely on cut-off rigidity, while for the conventional coordinate system this is not the case, cosmic ray intensity remains essentially a single-valued function of the cut-off rigidity. In view of this, it would seem that conventional geomagnetic coordinates are more appropriate to the problem, at least until more definitive information on cosmic ray coordinates becomes available.

In connection with the yield function (Fonger, 1953) used in these calculations, it should be noted that it is based on the latitude variation of the nucleonic component at 680 gm/cm² atmospheric depth (Simpson and Fagot, 1953). At this depth the latitude variation from high latitudes to the equator is approximately 2.55, somewhat larger than at sea-level (Rose et al., 1956) where the ratio is 1.77. Thus, the results of calculations involving this function are applicable principally at mountain altitudes; for lower altitudes a different yield function is required.

In the flare problem, the modulation function enters into the calculation of the latitude variation of flare radiation:

$$\left[\frac{\delta I(\lambda)}{I(\lambda)}\right]=\frac{\sum_{z}\int_{N_c(\lambda)}^{\infty}\left\{J_z(N)-j_z(N)\right\}M(N)S_z(N)dN}{\sum_{z}\int_{N_c(\lambda)}^{\infty}M(N)j_z(N)S_z(N)dN}$$

where $J_z\,(N)$ is the differential rigidity spectrum of flare radiation, assumed to be principally protons. Previous calculations (Meyer P. et al., 1956; Pfotzer, 1956; Kawabata et al., 1957) give an "effective" rigidity spectrum

$$J_{eff}(N)=M(N)J_z(N),$$

describing the radiation entering the main region of the earth's field after undergoing modulation. Using the modulation function obtained from the latitude variation of the

intensity decrease, the flare rigidity spectrum before modulation is given by

$$J_z(N)=J_{eff}(N)/M(N).$$

This correction for local modulation effects gives a closer estimate of the flare spectrum at the region of acceleration; however, it does not take into account possible effects resulting from the diffusion (Lüst and Simpson, 1957) of flare particles in magnetic fields near the flare site.

Data

Experimental observations (Brode; Simpson; Lockwood; Meyer B; Wilson; Wada; Brown, 1956) of the cosmic ray intensity variations obtained with twelve neutron monitors during February 1956 have been collected for comparison with the calculated latitude variation of modulation effects. In Table I are listed the neutron monitor

Table I

Location	Atm. Depth (gm/cm^2)	Latitude (deg.)	$\delta I. I/I$ (per cent)
Albuquerque, N. M.	860	43	7.5
Berkeley, California	1180	44	5.5
Chicago, Illinois	1000	53	8.3
Climax, Colorado	645	48	10.5
Durham, N. H.	1030	54	8.4
Göttingen, Germany	1000	52	9.4
Huancayo, Peru	645	-1	2.9
Leeds, England	1030	57	8.4
Mexico City, Mexico	760	29	4.9
Mt. Norikura, Japan	725	25	4.3
Sacramento Peak, N.M.	680	42	8.2
Mt. Washington, N.H.	820	55	9.2

locations, atmospheric depths, conventional geomagnetic latitudes and the magnitudes of the intensity decreases observed. The intensity variations listed represent a comparison of the minimum intensity during this disturbed period with the intensity in early January, just prior to the outburst of solar activity. In this connection, it is of interest to note that data from the Climax monitor (Simpson) indicates the cosmic ray intensity in early January was within 0.5 % of the value at solar minimum, mid-June 1954. Thus, the modulation effects in the period January-February 1956 may be attributed largely to the outburst of intense solar activity which occurred at that time.

Examination of the data in Table I shows that the magnitude of the intensity decrease at a low altitude station is generally less than that at a mountain altitude station at a nearby latitude. This is to be expected from the difference in yield functions noted above. In view of this result, only those variations obtained at high altitudes, where the yield function is fairly well known, were used in determining the modulation function during the peak of the intensity decrease.

Results

Of the three modulation functions, the second,

$$M_2(N)=\frac{N^{3/2}}{N^{3/2}+K_2}$$

with $K_2=3.0$, gave the best agreement between the calculated and observed intensity variations. The data listed in Table I, together with the calculated curve obtained with this function, are shown in Fig. 1. The other two modulation functions, when the

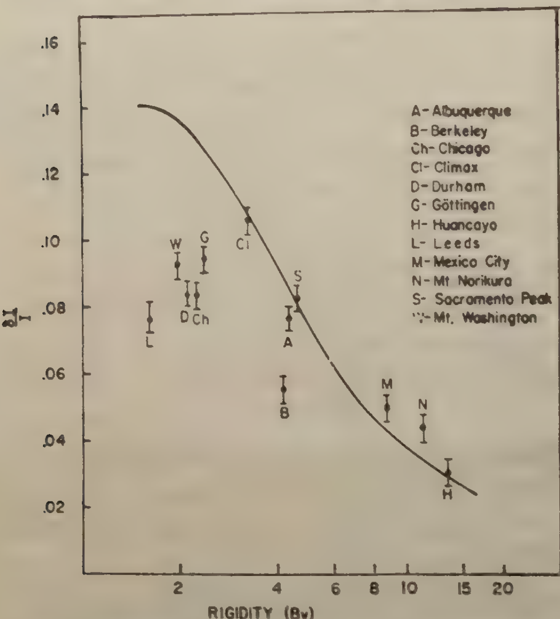

Fig. 1 Maximum intensity decrease observed with neutron monitors during February 1956 as a function of cut-off rigidity

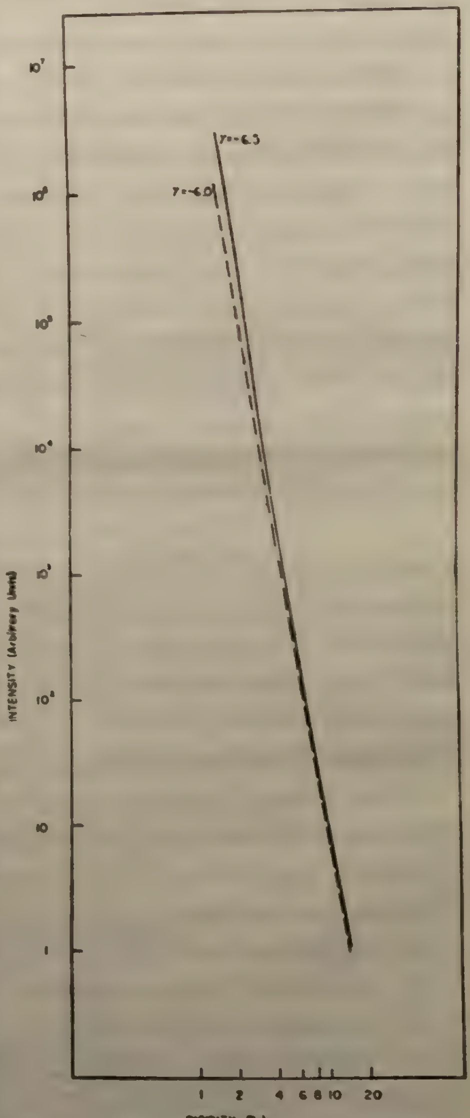

Fig. 2 Effective rigidity spectrum of flare radiation observed on February 23, 1956 and rigidity spectrum after carrection for modulation effects

constants were adjusted so as to give a 3% decrease at Huancayo, yielded calculated curves which departed from the experimental values obtained with high altitude monitors: the modulation function $M_1(N)$ proposed by Parker (1956) gave a variation (Brown, 1958) far in excess of the experimental points in going north from Huancayo while the function $M_3(N)$ brought the calculated curve down into the region occupied by the low altitude observations.

Correcting the "effective" rigidity spectrum (Meyer P. et al., 1956; Pfotzer, 1956; Kawabata et al., 1957) with this function steepens the spectrum of the flare radiation

as shown in Fig. 2; this is equivalent to increasing the magnitude of the exponent by approximately 0.5. Since the flare occurred about two days after the intensity minimum in February, this function gives an upper limit for the effects of modulating fields on flare particles. This limit is fairly close to the value for the time of the flare as may be seen from the increase in intensity just prior to the flare; for example, at Albuquerque (Brown 1956), the intensity just prior to the flare was 6.0 % below normal as compared to 7.5 % below at the minimum of the decrease.

Discussion

The modulation function obtained from the above analysis is less dependent on magnetic rigidity than the one proposed by Parker (1956). Thus, modulation effects are not limited only to low rigidity particles but also extend beyond the latitude sensitive portion of the primary spectrum. This slow variation of modulation with rigidity perturbs the spectrum of flare radiation to a small extent, increasing the magnitude of the exponent in the power law spectrum by approximately 10%.

Acknowledgment

The author is indebted to Mrs. Helen Hartmann for assistance with the numerical calculations.

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The modulation [illegible] [illegible]. The [illegible] not limited only to low rigidity [illegible] portion of the primary spectrum. [illegible] perturbs the spectrum of flare radiation to [illegible] the magnitude of the exponent in the power law spectrum by approximately [illegible]

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Magnetic Susceptibility of Orthopyroxenes*

By S. AKIMOTO, K. HÔRAI and T. BOKU

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(Read May 19, 1958; Received November 1, 1958)

Abstract

Magnetic properties of a series of orthopyroxenes, $x\,FeSiO_3\cdot(1-x)\,MgSiO_3$ separated from various kinds of rocks were examined. Paramagnetic susceptibility of the orthopyroxenes was determined from the slope of the straight line part of the magnetization curve, generally expressed as $\sigma=\sigma_0+\chi H$. The following empirical formula was obtained at the room temperature for the molecular magnetic susceptibility of the orthopyroxenes with varying x, i.e. $\chi_{mol}=1.12\,x\times10^{-2}$ e.m.u/mol. Using this experimental value and assuming that the Fe^{2+} ions are embedded isolately without any interaction between them in the orthopyroxene crystal, the effective Bohr magneton number of the Fe^{2+} ion was estimated to be 5.14 from the Curie's law. That this value is within the range of the accepted values of the ferrous ions in the crystal (5.1~5.55) seems to justify the above simple calculation.

1. Introduction

Although accurate knowledge on the magnetic properties of rook-forming ferromagnetic minerals has been accumulated steadily from recent studies, comparatively little work has been done on the magnetic properties of so-called non-ferromagnetic silicate minerals. Some rock-forming silicate minerals have been presumed to be paramagnetic from the qualitative consideration on their chemical composition, e.g. pyroxene, biotite, olivine etc. The only quantitative data reported hitherto are those by Nagata, Yukutake and Uyeda (1957) on the paramagnetic susceptibility of olivines.

In the present study, the magnetic susceptibility of some orthopyroxenes, solid solution between enstatite ($MgSiO_3$) and orthoferrosilite ($FeSiO_3$), of which constituting elements are quite similar to olivines has been measured in order to elucidate the magnetic behaviour of magnetic ions in the silicate minerals. The particular interest shown in the present paper is also related to the variation of the value of magnetic susceptibility with the ratio of enstatite to orthoferrosilite.

2. Specimens

The specimens used in the present study were offered by the courtesy of Prof. Kuno, Geological Institute, Tokyo University. The chemical composition of the specimens

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is given in Table I, where we can see the specimens cover almost whole range of orthopyroxenes.

Table I. Chemical analyses of orthorhombic pyroxenes.

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
SiO_2	57.63	55.73	54.11	53.32	51.00	48.95	48.06	46.56
Al_2O_3	1.20	0.93	1.52	0.88	1.47	0.24	1.21	0.23
Fe_2O_3	0.32	0.65	none	0.71	1.23	3.93	1.23	0.20
FeO	3.20	9.30	15.73	19.91	27.96	30.66	37.37	48.10
MgO	36.07	31.22	27.03	23.26	16.29	13.28	10.41	3.70
CaO	0.89	1.80	1.16	0.74	0.67	0.85	0.43	0.77
Na_2O	n. d.	0.21	n. d.	n. d.	n. d.	0.11	0.13	} 0.04
K_2O	n. d.	tr.	n. d.	n. d.	n. d.	0.03	0.05	
$H_2O(+)$	n. d.	} 0.32	n. d.	n. d.	0.11	0.08	0.12	n. d.
$H_2O(-)$	n. d.		n. d.	n. d.	0.01	0.16	0.02	n. d.
TiO_2	tr.	tr.	0.19	0.05	0.10	0.75	0.15	0.03
P_2O_5	none	n. d.	n. d.	n. d.	n. d.	n. d.	tr.	n. d.
MnO	0.02	0.15	0.34	1.22	1.16	0.93	1.16	0.15
total	99.33	100.31	100.08	100.09	100.00	99.97	100.34	99.78

Mineralogical description

No. 1 Enstatite from peridotite. Loc.; Kamogawa, Tiba Prefecture. H. Kuno, Study of orthopyroxene from volcanic rocks, Amer. Miner., **39**, 30 (1954).

No. 2 Bronzite from andesite. Loc.; Titi-zima (Bonin Island). S. Kozu and Y. Kawano, Bronzite from Titi-zima, Bonin Island, Jap. Ass. Mineral. Petro. Econ. Geol., Journ., **6**, 273 (1931).

No. 3 Bronzite from andesite. Loc.; Kônodai, Kagawa Prefecture,. H. Kuno, *op. cit.*

No. 4 Hypersthene from dacite. Loc.; Kentyô-zi (temple) at Kamakura, Kanagawa Prefecture. H. Kuno, *op. cit.*

No. 5 Hypersthene from dacite. Loc.; Sinkami-basi, Kagosima City. Unpublished analysis cited in this paper by the permission of Kuno.

No. 6 Ferrohypersthene from dacite. Loc.; Nagae near Taguti, Sidara Basin, Aiti Prefecture. Unpublished analysis cited in this paper by the permission of Kuno.

No. 7 Ferrohypersthene from gneiss. Loc.; Syowa Base, Antarctica. Unpublished analysis cited in this paper by the permission of Kuno and Katsura.

No. 8 Eulite from eulysite. Loc.; Wang-chang-tzu, Je-ho-shen, Northeastern Territory (Manchuria) of China. H. Kuno, *op. cit.*

Before the magnetic measurement was carried out, each specimen, after pulverized, was further purified by means of a Hallimond type magnetic separator in order to eliminate the ferromagnetic impurities as perfect as possible. The powder specimens which were separated into a trap *D* and *E* of the magnetic separator were used for the magnetic measurement. These are the last two stages of the magnetic separator, being considered to be extremely free from the ferromagnetic impurity.

3. Experiments

Two kinds of magnetic measurements were adopted by using a sensitive quartz spring magnetic balance described in a previous paper (Akimoto: 1954). The one is the measurement of magnetization curve at the room temperature, the other being the measurement of the variation in magnetization with temperature.

Typical examples of the magnetization curve are shown in Fig. 1-a and -b. The magnetization curve (σ–H Curve) of the orthopyroxenes is generally expressed as

$$\sigma=\sigma_0+\chi H \tag{1}$$

where σ, σ_0 and χ denote the measured magnetization, the spontaneous magnetization attributable to the ferromagnetic impurity and the paramagnetic susceptibility respectively. The magnetization curve shown in Fig. 1–a stands for the specimen which contains scarecely any amount of ferromagnetic impurity, while Fig. 1–b standing for the specimen which contains a considerable amount of ferromagnetic impurity. The paramagnetic susceptibility, χ of the specimen was determined from the slope of the straight line part of the magnetization curve. In actual process the mean value of a pair of measurement carried out on the fraction D and E was adopted for each specimen. The value of specific and molecular magnetic susceptibility at the room temperature is listed in Table II together with the molecular percent of the orthoferrosilite in the specimen. The situation that the magnetic susceptibility increases with content of orthoferrosilite nearly proportionally to the latter can be clearly seen in Fig. 2. The following empirical formula was obtained by the least square method from these experimental results at the room temperature,

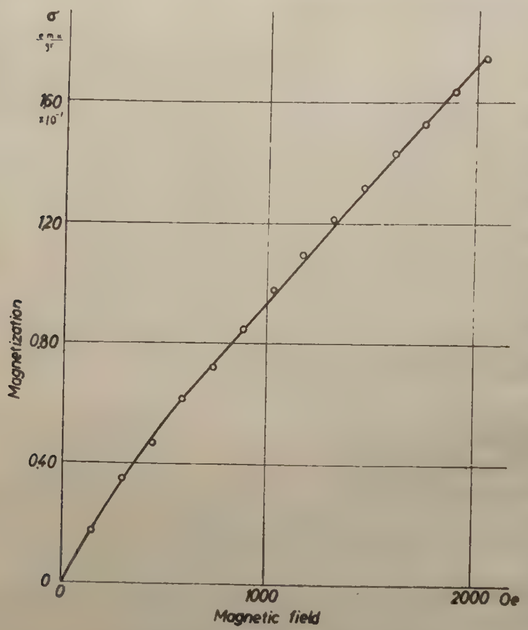

Fig. 1–a: Sample No. 8

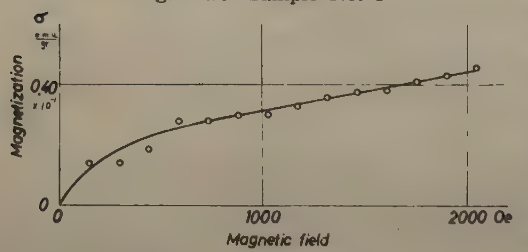

Fig. 1–b: Sample No. 2

Fig. 1 Examples of the observed magnetization curve of orthopyroxenes at the room temperature.

$$\chi_{mol}=1.12x\times 10^{-2} \text{ e.m.u./mol.}\ , \tag{2}$$

where x denotes the molecular percent of the orthoferrosilite.

In Fig. 3, typical examples of the change in the reciprocal magnetic susceptibility with temperature are given. The linear relation between the reciprocal magnetic susceptibility and the temperature shown in Fig. 3–a indicates that the specimen obeys the Curie's law satisfactorily. But the specimen with the magnetization curve such like Fig. 1–b manifests the temperature dependence given in Fig. 3–b, where we can

certainly see the existence of the ferromagnetic impurity of which Curie temperature is near that of magnetite.

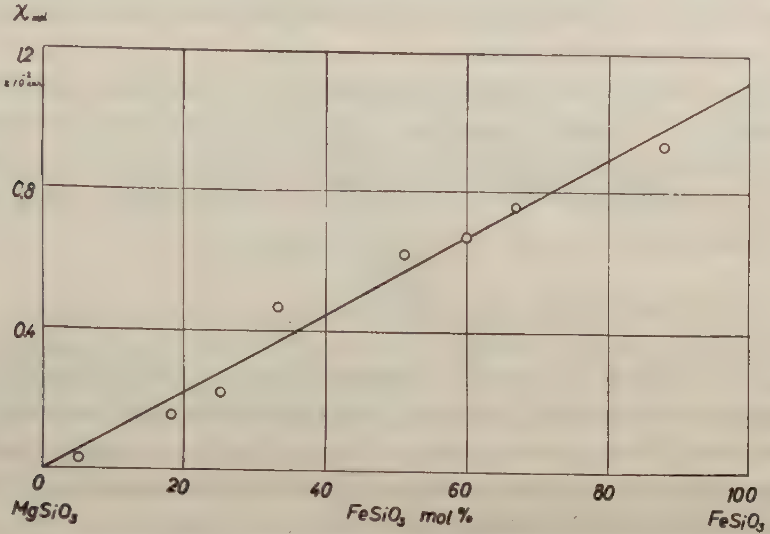

Fig. 2. Relation between the magnetic susceptibility of orthopyroxene and the orthoferrosilite content at the room temperature.

Table II. Magnetic susceptibility of orthopyroxenes.

Sample No.	$\frac{Fs}{Fs+En} \times 100$ in mol.	Paramagnetic susceptibility	
		specific, $\chi_{gr.}$	molecular, $\chi_{mol.}$
1	5	0.31×10^{-5}e.m.u./gr.	0.32×10^{-3}e.m.u./mol.
2	18	1.48 ,,	1.57 ,,
3	25	2.04 ,,	2.21 ,,
4	33	4.20 ,,	4.65 ,,
5	51	5.31 ,,	6.19 ,,
6	60	5.64 ,,	6.73 ,,
7	67	6.24 ,,	7.58 ,,
8	88	7.34 ,,	9.40 ,,

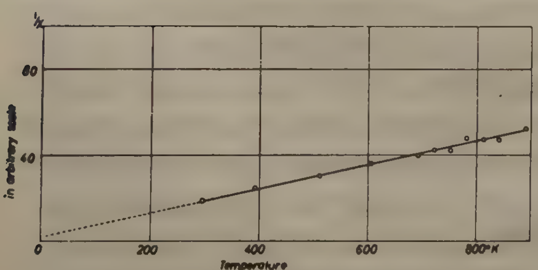

Fig. 3–a: Sample No. 8

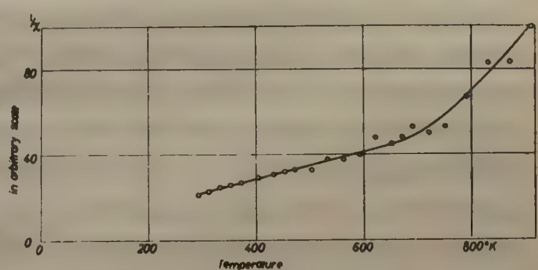

Fig. 3–b: Sample No. 2

Fig. 3. Examples of the variation of the reciprocal magnetic susceptibility of orthopyroxenes with temperature.

manns constant, the absolute temperature and the effective Bohr magneton number of the ferrous ions. Using the experimental values of χ_{mol} of orthoferrosilite in Eq.

Eq. (3) at T=...°C as

$$\mu_{eff}=5.14 \quad (4)$$

(Stoner: 1934)

of Fe^{2+} ions isolately embedded in

4. Discussions

From those experimental results described in section 3, it may be safely stated that the magnetic character inherent to the orthopyroxenes is paramagnetism originated from the ferrous ions in the crystal.

As was suggested by Nagata, Yukutake and Uyeda (1957), the paramagnetic susceptibility of orthoferrosilite should be expressed by the following formula, provided that the orthoferrosilite obeys the Curie's law completely; in other words, the magnetic moment of the ferrous ion is completely isolated from that of other ferrous ions without any interaction between them in the crystal.

$$\chi_{mol}=\frac{N_L\mu_B^2}{3kT}\,p^2_{Fe^{2+}}=\frac{0.124}{T}\times p^2_{Fe^{2+}}, \tag{3}$$

where N_L, μ_B, k, T and $p_{Fe}{}^{2+}$ are the Avogadro number, the Bohr magneton, the Boltzmann's constant, the absolute temperature and the effective Bohr magneton number of the ferrous ions. Using the experimental values of χ_{mol} of orthoferrosilite in *Eq.* (2), the effective Bohr magneton number of the ferrous ions can be enumerated from *Eq.* (3) at $T=20°C$ as

$$p_{Fe}{}^{2+}=5.14 \tag{4}$$

This value is within the accepted range of the effective Bohr magneton number of Fe^{2+} ion in the crystal (5.1~5.55). (Stoner: 1934)

These situations seem to support the idea that the magnetic property of the orthopyroxene is attributable to the paramagnetism of Fe^{2+} ions isolately embedded in the crystal structure.

The authors wish to express their sincere thanks to Prof. T. Nagata for his kind guidance and encouragement throughout the study. They also cordially thank Prof. H. Kuno who kindly allowed the authors to use the orthopyroxene samples separated by him. They are also indebted to Dr. S. Uyeda and Mr. T. Yukutake for their valuable discussions.

Note added

Since the present article was written, we have noticed that Prof. R. Chevallier and Mlle. S. Mathieu also studied the magnetic properties of pyroxenes. (1958) The specimens examined by them are the monoclinic pyroxenes. Their results are quite similar to those for the orthopyroxenes in our study. They stated that the measured paramagnetic susceptibility of the monoclinic pyroxene is also in good agreement with the calculated values from the Curie's law by using the accepted values of effective Bohr magneton number for Fe^{2+}, Fe^{3+} and Mn^{2+} ions contained in the monoclinic pyroxenes.

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Palaeomagnetic Researches for the Pliocene Volcanic Rocks in Central Japan (1)

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(Read October 26, 1958; Received November 28, 1958)

Abstract

All the rock specimens collected from middle Pliocene Komoro group and Shigarami group, have shown the marked magnetic polarisations in the direction of highly westward trend ranging roughly from N 60°W to N 110°W. The pole positions indicated by these specimens are calculated to be situated within a range from Lat. 32°N to Lat. 35°S.

A series of volcanic rocks including the middle Pliocene rock specimens abovementioned and ranging from early Pliocene to late Pliocene, seems to indicate that the pole position would have shifted continuously from Lat. 75°N to Lat. 70°S during Pliocene times.

As far as the writer's examination goes, it should be stressed that the direction of the earth's magnetic dipole axis in Pliocene age would have shifted from the North polar region, continuously southward to the South polar region.

1. Introduction

Researches for recognizing the direction of the Earth's magnetic field during geological times have extensively been made by means of natural remanent magnetism (*N.R.M.*) retained in rocks. In Japan, a series of studies on Quaternary rocks in volcanic region of Izu and Hakone district has hitherto been undertaken by the members of Nagata's Geophysical Laboratory (Nagata, Akimoto, Uyeda, Shimizu, Ozima, Kobayashi, and Kuno, 1957). Several noteworthy contributions have also been made to our knowledge by S.K. Runcorn (1955), P.M.S. Blackett (1956) and E. Irving (1956 and 1957) and other investigators. Palaeomagnetic studies are undoubtedly useful in considering both stability and origination of the Earth's magnetic field.

The physical basis for this possibility lies in the assumption that volcanic rocks might have obtained their magnetic polarisations having been influenced by the past geomagnetic field *in situ*—the so-called thermo-remanent magnetisation (*T.R.M.*) which volcanic rocks have acquired through cooling process. This assumption may simply be justified because it can easily be examined in our laboratory work. A bit of rock sample heated up to some 600°C, will acquire the remanent magnetism through cooling process. Thus acquired thermal remanent magnetism proves to be stable, indicating that its direction does coincide with that of the present geomagnetic field (Nagata, 1943 and 1953). These facts afford us a favourable condition for our purpose to research for

y publications (Nagata, Uyeda, and Akimoto, 1952; Nagata, Uyeda,

Kawai, Nomé and Sasajima, 1954; Uyeda 1955).

1) Both thermal demagnetisation curves made from N.R.M. and T.R.M. should be analogous in form.

should not take the value less than 0.2.

the past geomagnetic field during geological times.

Nevertheless, we suspect of the adequacy in applying this general principle of rock magnetism for all sorts of igneous rocks and in considering the stability of *T.R.M.* to have been enough resistant against various magnetic disturbances throughout so long geological times.

These suspections were at first araised through many discoveries of rocks with the reverse magnetism in contrast with the present geomagnetic field and later by the detection of the actual occurrence of self-reversal of *T.R.M.* In the case of magnetic minerals contained in dacitic pumice of Mt. Haruna, such an unexpected way of thermo-remanent magnetisation was found to take place during cooling process (Nagata, Akimoto and Uyeda, 1951).

This detection has naturally introduced numerous fundamental examinations as shown in many publications (Nagata, Uyeda, and Akimoto, 1952; Nagata, Uyeda, Akimoto and Kawai, 1952; Nagata, Akimoto and Uyeda, 1953; Akimoto, 1955 and 1957; Kawai, Kume and Sasajima, 1954; Uyeda, 1958).

For our purpose to recognize the past geomagnetic field by means of natural remanent magnetism of rocks, accordingly, following examinations will be needed.

1) Both thermal demagnetisation curves made from *N.R.M.* and *T.R.M.* should be analogous in form.
2) The ratio between the intensities of *N.R.M.* and that of *T.R.M.* namely *Jn/Jtc* should not take the value less than 0.2.
3) *N.R.M.* of rocks should be proved not to be the isothermal remanent magnetism by applying A.C. field demagnetisation.
4) Thermal variation of saturation-magnetisation should be traced along the same line with respect to both processes of heating and cooling.
5) Ferromagnetic minerals contained in rocks should be proved by X-ray analysis to be nearer to Fe_3O_4 in composition.
6) Rocks are available when they are proved to maintain their primary orientations and when the amount of dislocation of rock mass is known to us. In this respect, we are in need of consulting opinions of geologists.

The necessity of above-mentioned 6 ways of examination was propounded in 1954 by Nagata at the Rome meeting of I.U.G.G. Although these examinations are needed for both normal and reverse *N.R.M.* of rocks, they will, in particular, be needed in recognizing the past geomagnetic reversal. Two instances for which a firm conclusion was given by means of these examinations, have been known in Japan to show geo-magnetic reversal. The one was reported from volcanic region of Suwa (Nagata, Akimoto, Uyeda, Momose and Asami, 1955) and the another from that of Izu and Hakone district (Nagata, Akimoto, Uyeda, Shimizu, Ozima, and Kobayashi, 1957). Many publications among which Hosper's work (1953) is to be notable, have also been known outside of our country.

The majority of palaeomagnetic studies hitherto made over the whole world, however, has given us several informations that the pole positions of geomagnetic

dipoles locate mostly in the North and the South polar regions and few pole positions are located in the regions between the both poles. According to the studies hitherto made, few instances have been recognized in middle latitudes as those which show the transitional locations during the process of variation of dipole axis.

Although the examinations which should be applied for *N.R.M.* of rocks, have not yet been applied for all of the present samples, the obtained results seem to present a very serious conclusion. This is why the writer should like to present his conclusion which concerns only with the magnetic directions and the pole positions calculated from these measured rocks.

It naturally is impossible to obtain the values of intensity of *T.R.M.* before observing *N.R.M.*, but according to several examinations, the ratios Jn/Jtc were known to be within a range of 1.2–0.5 and the average 30% demagnetisations were observed in A.C. demagnetisation when $\tilde{H}=400$ Oe.

Each magnetic direction of several samples which were taken from the same rock mass in Komoro group, has indicated an ideal concentration within a range of 5°–7°, whereas each magnetic direction measured from samples in Shigarami group does not always show an ideal concentration. Some measured directions of the samples are observed to be roughly at right angle with the present geomagnetic field and some are observed to be reversed in a good concentration. Simply to say, these facts are likely to show that all the observed directions might have been due to stable magnetisation.

2. Measured magnetic directions and their geological ages

Neogene rocks in which abundant records of past volcanisms were maintained, have been extensively known in Shinshu of Central Japan. Researches for geology of this district have hitherto supplied numerous publications which inform us a sufficient knowledge with respect to their stratigraphic succession and geological ages.

It is hoped that we are able to collect many rock samples from every formations in a successive sequence in which any large hiatus might not be intervened. In this respect, both Komoro and Shigarami groups which are consisted of pyroclastic formations afford a favourable condition for the writer's work. According to Iijima and others (Iijima, Isawa, Koda and Taguchi, 1956; Iijima, 1956) volcanic records in both Komoro and Shigarami groups are thought to cover the whole extent of the Pliocene times.

The magnetic directions obtained and the pole position calculated from these are given in Table 1, where the magnetic directions obtained from these samples are arranged in descending order with respect to their stratigraphic succession.

The igneous rocks embeded in Komoro group are horizontally situated indicating no perceptible sign of lateral dislocation. They comprise such various rock types as welded-tuffs, basalts and intrusive bodies of porphyrites. Samples were taken from 9 localities being indicated by that their geological ages range from late Miocene to late Pliocene times.

[illegible]

It [illegible] is [illegible] observing N.R.M. [illegible] to be within a [illegible] in A.C. [illegible]

[illegible]

mass in Komoro group, has measured [illegible] whereas each magnetic direction [illegible] always show an ideal concentration, some [illegible] observed to be roughly at right angle with the present geomagnetic field and some are observed to be reversed in a good concentration. Simply to say, these facts are [illegible]

Table 1 Shigarami group

Localities	Rock Names	Direction		Directions of the Centred dipole	
Konabe	(Ho.) py. Andesite	N 60° E	5°	26° N	119° W
Akefuji bashi	Ol. py. Basalt	N 18° E	55°	75° N	141° W
West of Okkayo	2 py. Andesite	N 20° E	64°	72° N	175° W
West of Akefuji bashi Ⓐ	(Ho.) 2 py. Andesite	N 69° W	−68°	15° S	8° W
West of Akefuji bashi	(Ho.) 2 py. Andesite	N 94° W	−22°	8° S	38° E
Kawashimo Ⓐ	(Ho.) 2 py. Andesite	N 70° W	50°	32° N	62° E
Kawashimo	(Ho.) 2 py. Andesite	N 77° W	27°	17° N	50° E
Machi	Ol. py. Basalt	N 89° W	−46°	15° S	23° E
East of Doai	(Ho.) 2 py. Andesite	N118° W	−42°	35° S	38° E
Kuroiwa	Ol. py. Basalt	N167° E	−34°	70° S	174° E

Komoro group

Fukazawa 1	Basalt	N 19° E	61°	74° N	169° W
Fukazawa 2	Basalt	N 13° E	64°	75° N	175° E
Ōya	Welded tuff	N 64° W	−22°	12° N	20° E
Higashi zawa	Welded tuff	N 79° W	14°	12° N	44° E
Miyanoshita	Porphyrite	N 74° W	−52°	8° S	9° E
Sehaya gawa Ⓐ	Basalt	N102° W	−63°	32° S	9° E
Sehaya gawa	Welded tuff	N153° W	−45°	65° S	58° E
Hanare yama	Welded tuff	N155° W	−36°	63° S	70° E
Yasuhara	Welded tuff	N155° W	−47°	67° S	59° E

Apart from the two samples collected from the uppermost part at Yasuhara and the lowermost part at Fukazawa, most samples ranging from middle to late Pliocene, indicate the magnetic directions of highly westward trend.

According to the prevailing aspect on the absolute time length of the whole Pliocene, it has been measured to cover enough 10^7 years. In this respect, it should be stressed that the period when geomagnetic field was in a highly westward direction lasted for a considerable time length of the Pliocene. Seeing that these rocks are in a conformable sequence, we ought to have detected any other direction, if the period was intervened once by a time when geomagnetic field was not in a highly westward direction.

On the other hand, Shigarami group which is composed of pyroclastic rocks including numerous lava flows mainly of hornblende-2 pyroxene-andesites overlies conformably the marine late Miocene Ogawa group. Shigarami group as a whole is not thought to bear any marked stratigraphic break. Unlike the rocks of Komoro group, certain disturbances are, in some localities, recognized to have occurred since the formation of rock masses. As the writer has experienced, magnetic directions obtained from several samples of Shigarami group do not always indicate an ideal concentration. At several localities, rock masses were known to have been dislocated, consequently it was necessary to restore the measured magnetic directions in order to obtain the past geomagnetic directions. Most samples from Shigarami group show that they have

Table 2

Geologic age		Shigarami group		Komoro group		Volcanic rocks around Lake Suwa		Direction
Quaternary	Pleistocene							
	— ? —				Ōkubo (and.)		Takaosan (and.)	N
Tertiary	Up. Pliocene	Sarumaru Form.	Kuroiwa (basalt)	Nunobiki Form.		Enrei Form.	Utsukushi-ga-hara up. part Utsukushi-ga-hara low. part Mitu-mine, Suwa up (all and.)	Re
			east of Doai (and.)	Up. Ōkui Form.	Hanareyama, Yasuhara, Sehayagawa Ⓐ (w.t.)		Kawagishi, Dōda, Suwa low, part Wada Pass (all and.) Wada (lip.)	Rw
	Mid. Pliocene	Shigarami Form.	Machi (basalt) Kawashimo (and.) Kawashimo Ⓐ (and.) West of Akefuji bashi West of Akefuji bashi Ⓐ (and.)		Sehayagawa (basalt) Porphyrite Higashizawa, Ōya (w.t.)			Rw
	Low. Pliocene		West of Okkayo (and.) Akefuji bashi (Basalt)	Low. Ōkui Form.	Fukazawa (basalt)			Ne
	Miocene		Konabe (and.)					

Form. : Formations and. : andesite w.t. : welded tuff lip : liparite

... intrusive body (perhaps late Pliocene) at ...

As compared with Nomori group, several localities in Shiozumi group are somewhat disfavoured by a little unfavourable conditions as noted in the foregoing ... a number of obtained magnetic directions ... are comparable with ... from Nomori group, indicating the trend of contemporaneous geomagnetic ... during Pliocene time because both groups are thought to be almost contemporaneous with one another.

Correlation chart inferred from geologic and palaeomagnetic data.

Besides these, samples collected from Kimi group ... (1955) afford a ... studies. Kimi group is a thick lacustrine group of ... its geological age ... to be the later half of the Pliocene. As a report will be published in the near future, the writer will here not go into detail as to the palaeomagnetic studies of Kimi group.

... s seen in Table 2, the upper ... formation ... Shiozumi group are comparable in age, and the former ...

been magnetised in a distinctive westward direction, except for those of the lowermost lavas (latest Miocene or earliest Pliocene) at Okkayo and Akefuji-bashi, and those of basaltic intrusive body (perhaps late Pliocene) at Kuroiwa.

As compared with Komoro group, several localities in Shigarami group are somewhat disfavoured by a little undesirable conditions as noted in the foregoing paragraph, a number of obtained magnetic derections, however, are comparable with those afforded from Komoro group, indicating the trend of contemporary geomagnetic secular variations during Pliocene times, because both groups are thought to be simultaneous with one another.

3. Correlation chart inferred from geologic and palaeomagnetic data

Besides these, samples collected from Enrei group (Kobayashi, 1958) afford a better understanding for our palaeomagnetic studies. Enrei group is a thick lacustrine group of formations interbedding numerous lava flows and indicating its geological age to be the later half of the Pliocene. As a report will be published in the nearest future, the writer will here not go into detail as to his palaeomagnetic studies of Enrei group, citing only the observed magnetic directions.

Correlations between these groups by means of geologic and palaeomagnetic data are made in Table 2. As seen in Table 2, the upper Okui formation of Komoro group and the upper part of Shigarami group are comparable in age, and the former

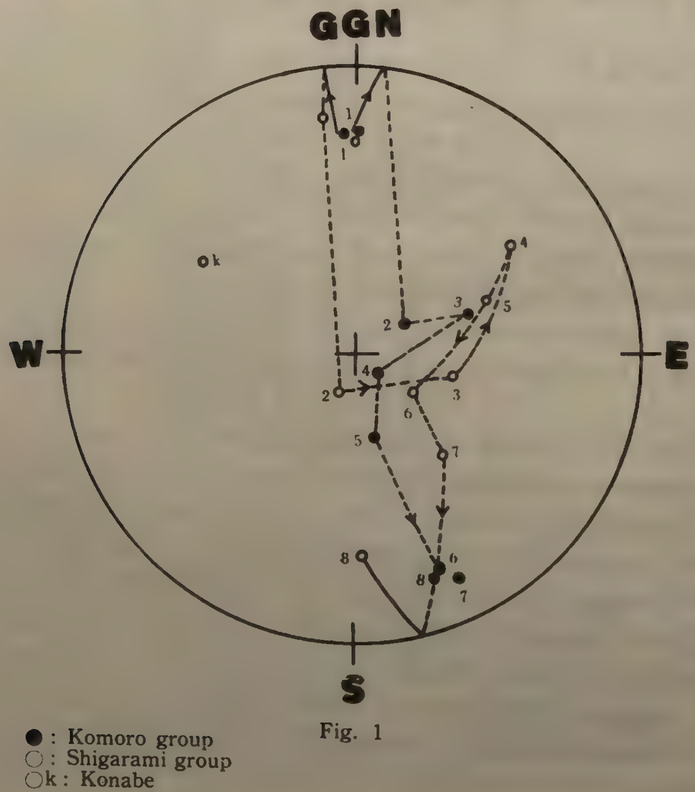

Fig. 1

is also able to be comparable with the lower part of Enrei group. So important is the fact that the probability of these correlations is supported not only by geologic basis but also by palaeomagnetic researches.

4. Variation of geomagnetic dipole

The pole positions enumerated in Table 1 are put in Fig. 1. The pole positions in Fig. 1 may be traced in the order from 1 to 8, which signifies the stratigraphic succession in ascending order. Black dots indicate the pole positions obtained from samples of Komoro group, showing the trend of shifting from Alaska by way of Bering Sea, central part of Africa and Cape Town to the South polar region, while those of Shigarami group being indicated by white dots show the shifting from the North polar region by way of eastern part of Africa to the South polar region. Although both trace lines of shifting do not show a complete coincidence with one another, the modes of both lines as a whole seem to be analogous with one another. It would be hoped that a better coincidence might be obtained if the restorations of actual directions measured from the rock masses of Shigarami group were not needed.

S.K. Runcorn (1955) gave various disscussions as to the probability of polar variation which might have taken place since older times of pre-Cambrian and Cambrian down to younger geological times. E. Irving (1956 and 1957) on the other hand, gave a discussion in which he propounded a plausible hypothesis of polar wandering. But it is likely to say that the features of variation of pole positions during Pliocene times have not yet been better known to many researchers. The present conclusion which the writer has confirmed for many years, will present the occurrence of a new type of polar variation different from that which may be assigned to polar wandering.

The writer will be fortunate enough if his works might offer a bit of contribution to the theoretical researches for the origination and the maintainance of the Earth's magnetic field.

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in Fig. 1 ... succession in ...

samples of Komoro group, showing the trend of shifting from Alaska by way of Bering Sea, central part of Africa and Cape Town to the south polar region, while those of Sugadaira group being indicated by ... the shifting from the North polar region by way of eastern part of Africa to the South ... trace lines of shifting do not show ... with one another ... of both lines as a whole seem to be analogous with one another. It would ...

S.K. Runcorn (1965) gave various discussions as to the probability of polar variation which might have taken place since older times of pre-Cambrian age ...

say that the features of variation of pole positions during Pliocene times have not yet ... present conclusion which the writer has

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The Electrical Structure of Thunderstorms

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(Read May 17, 1958 ; Received November 30, 1958)

Abstract

The simultaneous observation of the thunderstorm electricity was made at eight stations during the summer of 1957. The potential-gradient changes from a number of lightning flashes were analyzed. Within the cloud, the electric moments were destroyed at the height from 4km to 7km and the values of the moments were distributed to the extent of 70Ckm. By the cloud-ground flashes, negative charges so far as about 30C were transfered to the earth through a distance from 4km to 11km. The cloud flashes and the earth flashes occurred at different horizontal positions in the cloud, as well as at different levels. Referring to the aerological data, the location of the charge center or the charge-separation level was related with the air temperature. The average results give a picture of a thunderclound similar to that of double dipole by Kuettner.

I. Introduction

One of the most important problems of the thundercloud is the determination of the arrangement of the charges in the cloud and their magnitude, and there has been considerable debates as to this problem. To solve this problem, a series of observations of thunderstorm electricity were made in the vicinity of Kyoto City, Japan, during the summer of 1957. The observations had been planned to be made both on the ground and in clouds. However, the observations in clouds with radiosonde and sounding balloons were not successful enough to be analyzed. On the ground the potential-gradient changes due to thunderstorms were measured simultaneously at the 8 stations.

It is possible to determine the magnitude and the location of the charge transferred in the flash by the use of this network on the ground. This was first used by Workman, Holzer and Pelsor (1942), and extended by Reynolds and Neill (1955). It was proved that the method was appropriate to the study of New Mexico thunderstorms. Hatakeyama (1946) also carried it out in Japan. For the South African thunderstorms, Barnard (1951) and Hacking (1954) also used this method to obtain information on the negatively charged column taking part in a cloud-ground discharge.

During the period of the observation, about 20 thunderstorms were observed by the network. Although 15 storms gave sufficient data to all or almost all the stations in the network, 8 thunderstorms were analyzed for the present investigation, while other 7 storms were too violent or too distant.

2. Method of Observation

The network consists of the 8 stations distributed over a circular area of about 17km in diameter. As shown in Fig. 2 the distance between the neighboring 2 stations is 5–7 km and the level difference between the highest station (Otsu, 91m asl) and the lowest (Chusyozima, 16m asl) is 75m.

The value of potential gradient at each station was reduced to the plane value using the reduction factor obtained by absolute measurements by means of polonium collector and static voltmeter.

The field meter used for the measurement of potential gradient is of a generating voltmeter type, originally devised by Hasegawa (1940) and afterwards improved to the portable type by Tamura (1956). Working principle of the field meter is the same as that of Workman and Holzer (1939) and Gunn (1949). This apparatus faithfully follows the field change accompanying a lightning flash, the recovery of the field after that, and also the slow variation of the field.

3. Typical Example of the Record

Fig. 1 gives the reproduction of the electric field records simultaneously obtained at the 8 stations. This part of the record is preceded by similar characteristic features of a distant storm for about 15min. At the C station (Otsu) nearest to the thunderstorm, record runs out of the scale in the most active period. And at the most distant station B (Saga), there can only be seen both positive and negative sudden changes due to lightning flashes.

The last part of the record corresponds to the last phase of the storm activity. Occurrence of negative field changes in succession show the characteristic feature of the dissipating stage of a thunderstorm cell.

As the results of analysis of this example of the record, it was found that the positive field changes, produced everywhere in the network, show the earth flash, carrying negative charge to the ground and the negative field changes show the cloud flash, destroying the electric moment within the cloud (refer to Figs. 2 and 3).

The part showing the straight lines in the records corresponds to the interruption of the electric supply for the observation.

4. Method of Analysis

With the observation arrangements mentioned above can be found the position of the charge center and the magnitude of the charge neutralized by a lightning flash, if some assumptions are adopted as follows.

The surface of the earth is an infinite conducting plane, and all the stations are on the plane surface, ignoring the topographical irregularity, and then all the thunderstorms appear over the plane surface. The lightning flash involves the neutralization of a spherical charge. Besides, doublet distribution of the charges is assumed in the case of intra-cloud flash. The doublet distribution, as has been pointed out by Fitzgerald (1956), gives nearly the same electrical effect on the surface of the earth as a

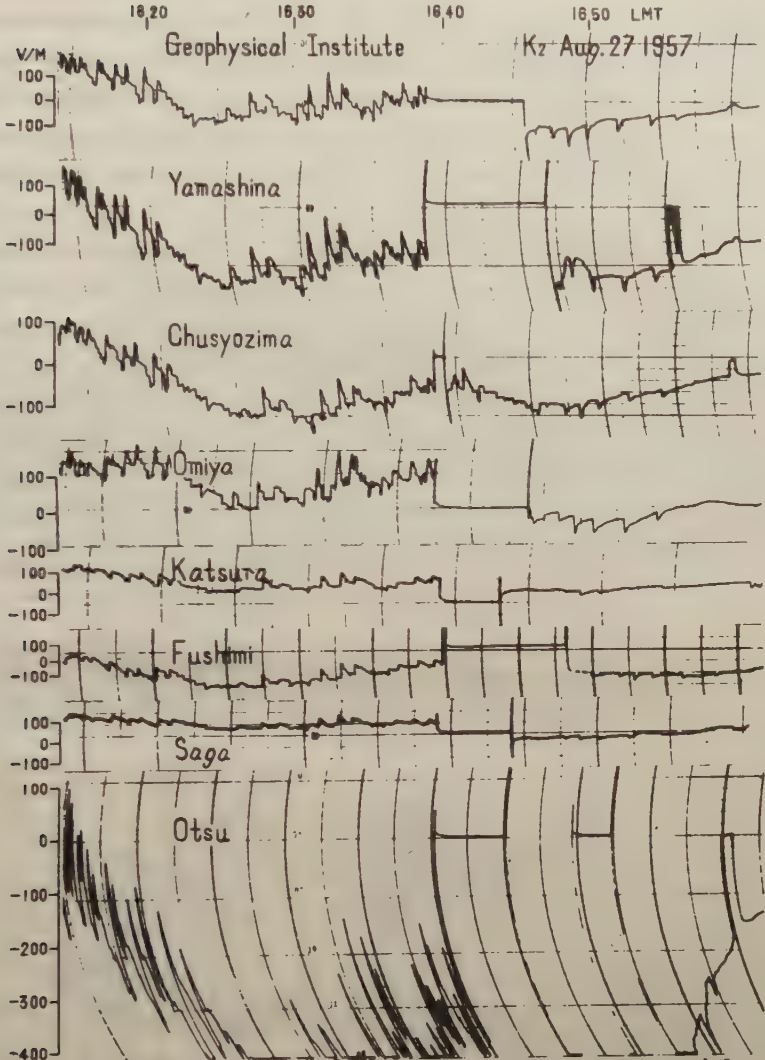
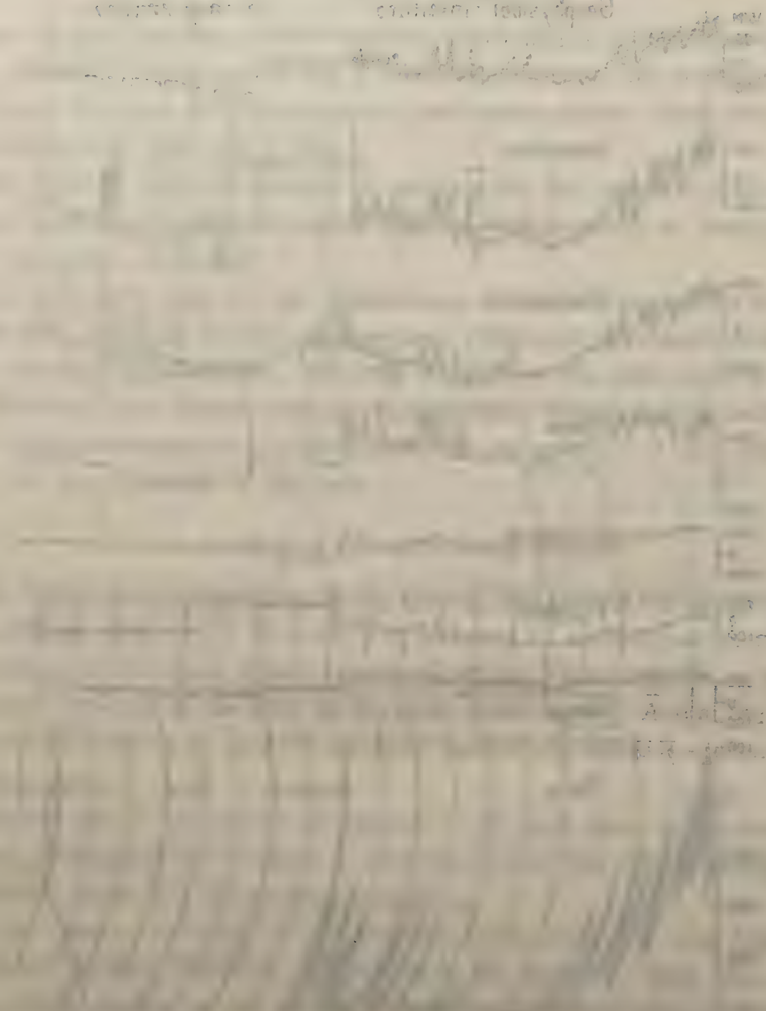


Fig. 1 Simultaneous records of the electric field at eight stations; thunderstorm K_2 : August 27 1957

dipole charge distribution having relatively small separation of poles and the equal electrical moment. It is considered, however, the position of the doublet can only give the height of the charge separation in a cloud.

There can be seen 3 cases of the sudden field change in the record simultaneously obtained by the network; that is, 1) changes are positive at all stations, 2) negative at all stations and 3) positive at several stations and negative at others. As the first step of analysis, it is guessed from the distribution of the field changes whether a flash is within the cloud or from cloud to earth, and a few considerations are made about the most possible causes of these field changes. In the case of 1), field changes are from a flash carrying negative charge to the ground. In the case of 2), field changes are from a flash of positive polarity in the cloud and all the stations are located in the



domain of negative field changes. In the case of 3), field changes are from a flash in the cloud. Although the most attention was paid to the above 3 possibilities, but other possible causes for the field changes were also taken in consideration. For example in the case of 2), it was examined carefully whether there was a cloud-ground discharge carrying positive charge to the ground, about which several reports have been proposed, or not.

As a means of analysis, many series of electric field maps by a single charge, corresponding to the earth flash, or a doublet, corresponding to the cloud flash, were drawn. For the single charge, models of every 500m heights were prepared; for the doublet distribution, models of every 500m heights with the doublet axis of 0 (vertical), 1/10, 2/10, 3/10 and 4/10 were prepared. It is interesting that many cases of field-change distributions corresponding to flashes within the cloud are in good agreement with the doublet models having nearly vertical axis. Even in other cases, the inclinations of axis were enough to be 2/10 or 3/10 at most. Hatakeyama (1946) also reported that the lightning flashes were nearly vertical.

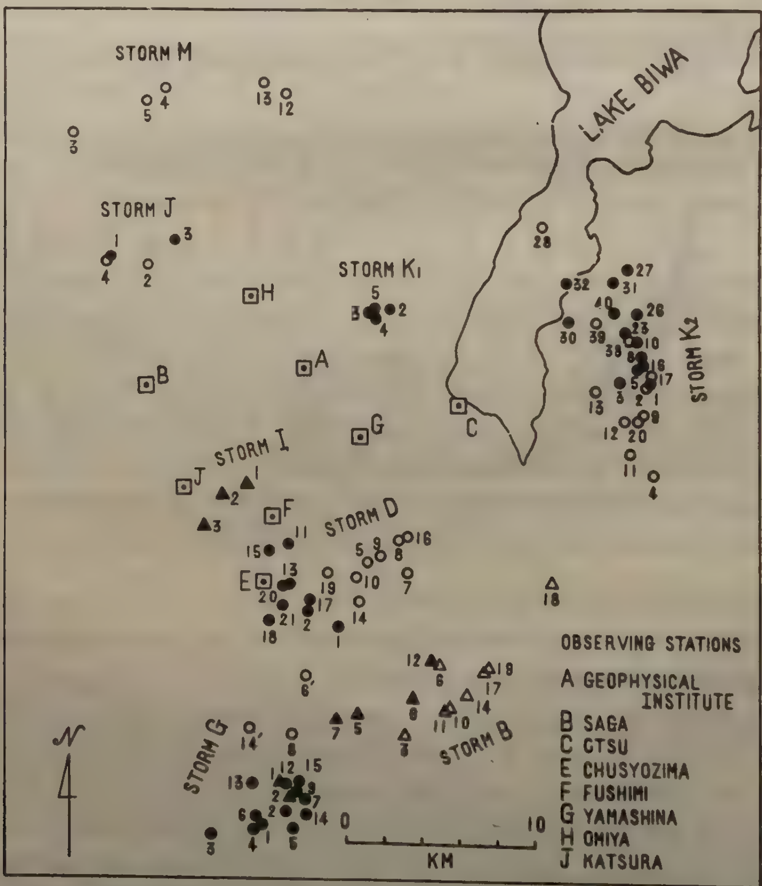


Fig. 2 Distributtion of epicenters of a discharge; thunderstorms (1957)
B: July 22, D: August 4, G: August 16, I: August 23, J: August 26, K_1: August 27, K_2: August 27 and M: August 27,
black mark: cloud-ground discharge, white mark: intra-cloud discharge

In this way, the field change distributions simultaneously obtained by the network were examined by the above models. By this graphical method, a number of electric field changes were analyzed and other considerable numbers of them seemed to be difficult to analyze.

As the models of field distribution are discrete, the results of analysis are necessarily discrete. Error in estimating the location of the charge center is 500m at the most at horizontal position as well as at vertical level.

5. Results of the Analysis

Eight thunderstorms were analyzed with respect to the field changes accompanying the lightning flashes. Fig. 2 gives the 'epicenters' of the earth flashes or the cloud flashes, where the 'epicenter' represents the projection on the ground of the center of the charge neutralized by the cloud-ground discharge and the same representation is adopted for the intra-cloud discharge. The numbers by the marks show the order of the lightnings. There can be pointed out the progressive character in the storms B, I, K_2 and M, that is, the epicenters, as a whole, walk to one direction at

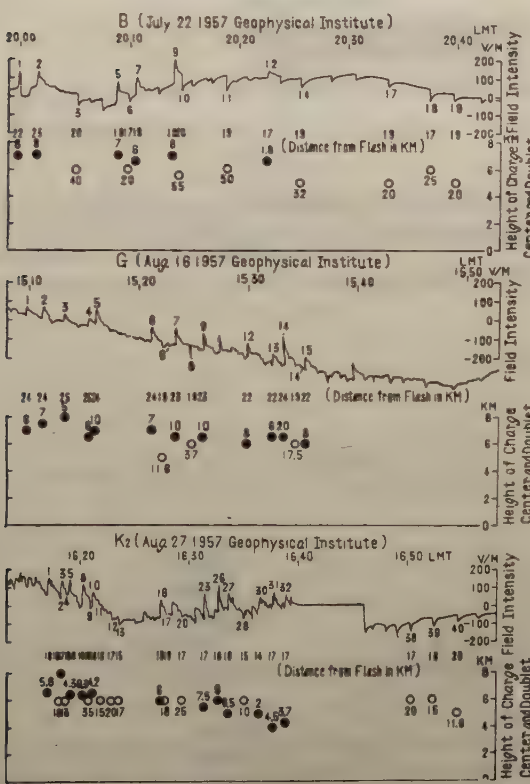


Fig. 3 Heights of negative charge center (black mark) and doublet (white mark) with magnitude in coul. and in coul.km respectively, and for reference, with electric field record and distance from flash; thunderstorm B, G and K_2

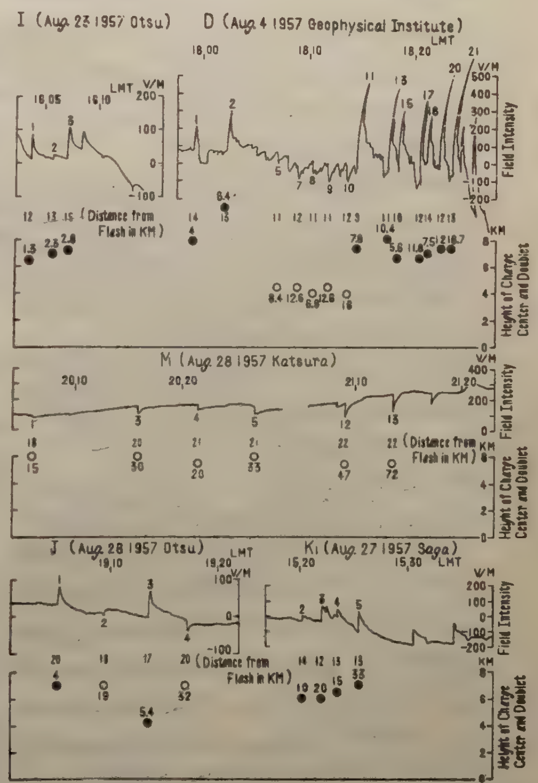


Fig. 4 Heights of negative charge center (black mark) and doublet (white mark) with magnitude in coul. and in coul.km respectively and for reference, with electric field record and distance from flash; thunderstorm D, I, J, K_2 and M

6. Results of the Analysis

... with respect to the cloud charges ... ing the lightning flashes. Fig. 2 gives the epicenters of the earth flashes or the cloud flashes, where the epicenter represents the projection on the ground of the center of the charge neutralized by the cloud or earth discharge and the same representation is adopted for the intra-cloud discharges. The numbers by the marks show the order of the discharges. There can be pointed out the progressive character in the storms B, I, K, and M, that is, the epicenters, as a whole, walk to one direction as

Fig. 2

random step by step. This is the first remarkable fact. The second remarkable fact noticed in Fig. 2 is that the cloud flashes and the earth flashes occurred at different horizontal positions and that the former seemed to lag behind the latter. This is shown in the storms B, D, G and K_2.

Figs. 3 and 4 show the heights of the centers of the negative charges with their magnitudes (in the case of cloud-ground discharges), the heights of doublets with their electric moments (in the case of intra-cloud discharges) and also the distances of epicenters from the stations with one record example showing the corresponding field changes. The numbers by the marks show the values of the charge quantity or the electric moment. The numbers by the sudden changes in the record example show the order of the discharges. It is noticeable result that the center of the charge neutralized by a cloud-ground discharge is often at higher level than the doublet whose height probably represent the level of separation of charges neutralized by a intra-cloud discharge. It is also interesting that, with some exceptions, the height of the negative charge center changes systematically with lapse of storm time, but the height of the doublet remains nearly constant.

6. Conclusions

Results obtained from the present analysis may not be the best samples for all thunderstorms but these are useful to get a model of the electrical structure of the thunderstorm.

In one part of a thunderstorm cloud there is a center of negative charge which is neutralized by the cloud-ground discharges. The height of this center ranges from 4km to 11km. Apparently separated from the negative charge center horizontally as well as vertically, there is another part where intra-cloud discharges occur. The height of separation of positive and negative charges in this part ranges from 4 km to 7 km.

Temperature is considered the main determining factor in the position of electric charge in the cloud. In Kyoto the temperature data of the upper air was not obtained during the observation period. Referring to the aerological data at Yonago, 230km WNW from Kyoto, and Shionomisaki, 175km south from Kyoto, the temperature at height of a charge center or a doublet was estimated. As the temperatures have nearly the same

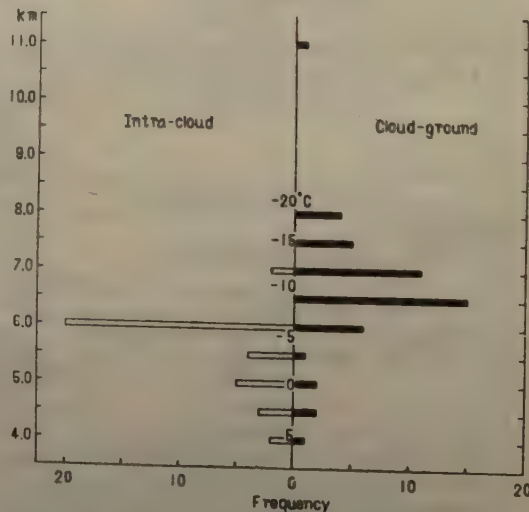


Fig. 5 Frequency of positions of negative charge (cloud-ground discharge) and doublet (intra-cloud discharge) according to temperature and height

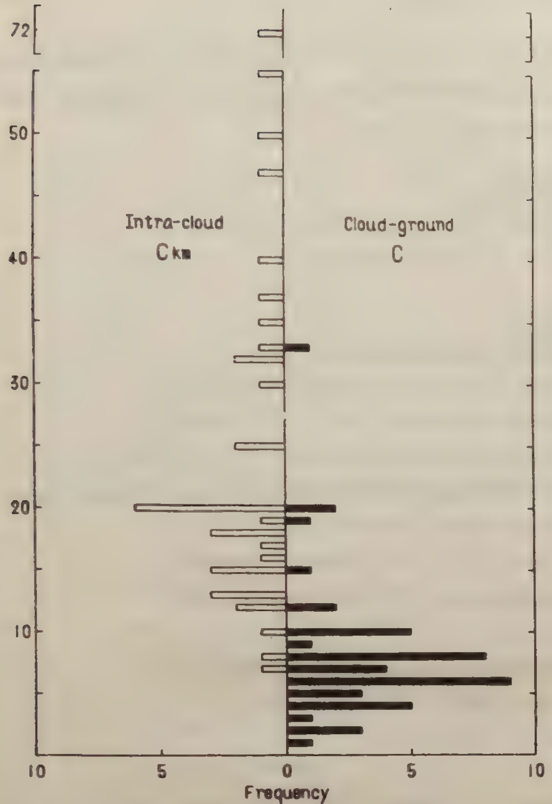


Fig. 6 Frequency of magnituds of negative charge (cloud-ground discharge) and doublet (intra-cloud discharge)

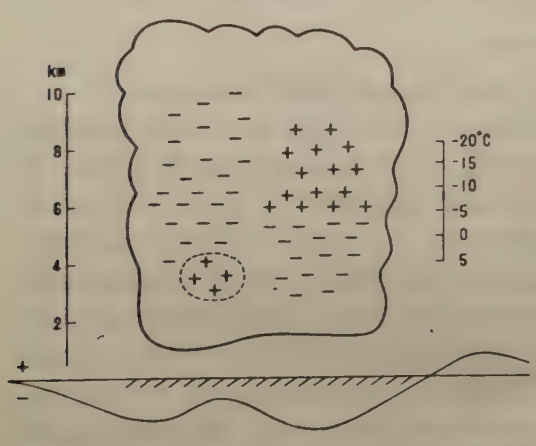


Fig. 7 Thundercloud model showing distribution of electricity and potential gradient on the ground

values at the both stations, it is supposed that the temperature at Kyoto can not deviate from the mean value so much. The frequency distribution of the charge or the doublet with respect to the temperature or the height is shown in Fig. 5.

Fig. 6 gives the frequency distribution of the magnitude of the negative charge moving to the earth or the electric moment destroyed within the cloud.

As to the lower positive charge at the base of a cloud, this method of analysis can give no certain indication. In many cases, however, a thundercloud is found to give a large negative potential gradient when approaching, but when overhead, there is a decrease, more or less, in the negative potential gradient. This will suggest the thundercloud having the lower positive charge at the base. Also in general, it is recognized that the lower positive charge is necessary for the initiation of a cloud-ground flash. If this charge is located at the base of the negative charge column, the present results give a picture of a thundercloud similar to that of Kuettner (1950) having two dipoles, one of which is of positive polarity and the other is of negative polarity. This is shown in Fig. 7. As shown in three examples of the thunderstorms B, G and K_2, at the later stage of storm activity only the positive polarity remains. So far as the thunderstorms analyzed here, their character seems to be simple. However, as the number of storms is small, the conclusions are necessarily tentative. Further investigations are desirable.

Acknowledgements

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Polar Ionospheric Disturbances Associated with a Severe Magnetic Storms

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(Read May 18, 1958; Recieved December 3, 1958)

Abstract

A detailed investigation is made of a severe magnetic storm on October 28th 1951, using world-wide simultaneous geomagnetic and ionospheric data. It has been found that an outstanding electrojet stream comparatively short-lived appeared near the southern edge of the auroral zone at the end of the main phase of this storm. The ionospheric disturbance associated with this electrojet was anomalous; the electron density of the $F2$ layer above the electrojet stream increased suddenly to more than 10^6 electrons per cm^3 and then dropped below normal after the disappearance of the current stream.

Although any existing theory of ionospheric storms can not explain satisfactorily this anomalous change, two possible mechanisms are suggested from some consideration of the direct association of geomagnetic and ionospheric variations. One is the effect of the incomming corpuscular precipitation into the ionosphere and consequently the formation of a new $F2$ layer due to the increase of ionization. The other is due to the vertical drift of electrons produced by the interaction of the geomagnetic field with the currents in the $F2$ region returning from the main electrojet formed in the E region.

Introduction

Geomagnetic storms and associated ionospheric disturbances are the most outstanding phenomena in the earth's upper atmosphere, and there has been carried out a number of investigations concerned with them. The morphology of geomagnetic storms was started as early as in 1918, and extensive studies were made mainly by Chapman and his colleagues (1918, 1927). The effect of the ionosphere (F-2 layer) associated with geomagnetic storms was also investigated by earlier workers and recently by Appleton (1952), Martyn (1953) and the Japanese group (Nagata, 1954; Obayashi 1954; etc.). Systematic world-wide characteristic of geomagnetic and ionospheric storms, such as the storm-time variation and the diurnal disturbance variation, have been derived with their comprehensive statistical analyses. It has also been suggested that there exists some close relation between those worldwide disturbance pattern of the geomagnetism and the ionosphere.

Thus, in the present stage of the investigation, it seems that the general aspects of the "average" geomagnetic storms and F-2 ionospheric disturbances are established fairly well. However, more detailed analysis is still necessary in the polar regions to

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A detailed investigation is made of a severe magnetic storm [illegible], using world wide simultaneous geomagnetic and ionospheric data. It is found that an outstanding electrojet stream [illegible] storm. The ionospheric disturbance associated with this electrojet was anomalous: the electron density of the $F2$ layer above the electrojet stream increased suddenly to more than 10^6 electrons per cm^3 and then dropped below normal after the disappearance of the current stream.

Although any existing theory of ionospheric storms can not explain satisfactorily this anomalous change, two possible mechanisms are suggested from some consideration of the direct association of geomagnetic and ionospheric variations. One is the effect of the incomming corpuscular precipitation into the ionosphere and consequently the formation of a new $F2$ layer due to the increase of ionization. The other is due to the vertical drift of electrons produced by the inter- [illegible]

confirm a direct connection of the geomagnetic disturbance field with corresponding ionospheric changes. Actually it has been known that, unlike the features of the average magnetic storm derived from the statistical study, individual polar magnetic storms are composed of a number of elementary disturbances which are taking place intermittently or successively in the auroral zone (Fukushima, 1953). Therefore, it is important to find out the exact ionospheric changes which are related to such an elementary magnetic disturbance. Nevertheless, this problem has not yet been well studied, owing to the difficulty of collecting a sufficient number of simultaneous world-wide geomagnetic and ionospheric data.

Fortunately, the recent establishment of a North-American network of observatories provides a good opportunity to study the above-mentioned problem. In the present paper there is described in detail an outstanding ionospheric change during a severe magnetic storm on October 28th, 1951, and an attempt is made to find out a possible physical mechanism of ionospheric variations as related to the formation of an intense electrojet stream near the auroral zone.

Anomalous Ionospheric Changes Associated with a Severe Magnetic Storm on October 28th, 1951.

A severe magnetic storm occurred at 11h 54m U.T. on October 28, 1951 with a sharp sudden commencement. As will be shown by the magnetic record observed at College, Alaska in Fig. 1, the storm was composed of a number of intense local disturbances, each of which continued an hour or so successively during the very pronounced main phase. Since this storm was a typical intense one of comparatively short

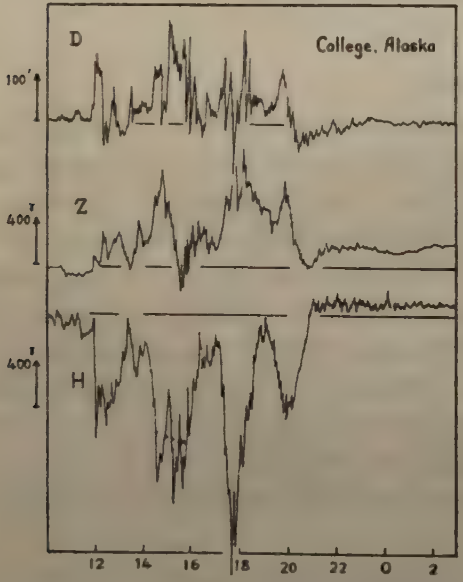

Fig. 1 Record of the magnetic storm of Oct. 28–29, 1951 at College, Alaska.

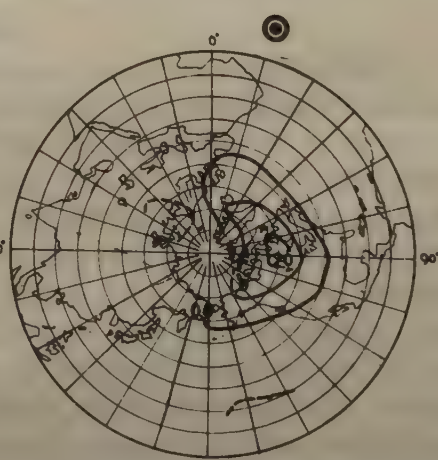

Fig. 2 Distribution of $f^\circ F2$ during Initial Phase of Magnetic Storm at 13h U. T. on October 28, 1951.
(In Figures contour lines are drawn at intervals of 1.0mc/s $\Delta f^\circ F2$)

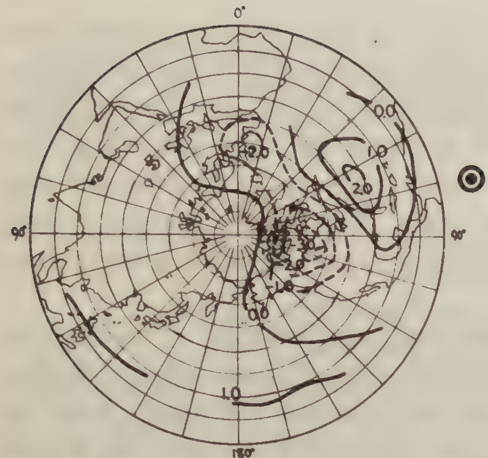

Fig. 3 Distribution of $f^{\circ}F2$ during the Main Phase of Magnetic Storm at 17h U.T. on October 28, 1951.

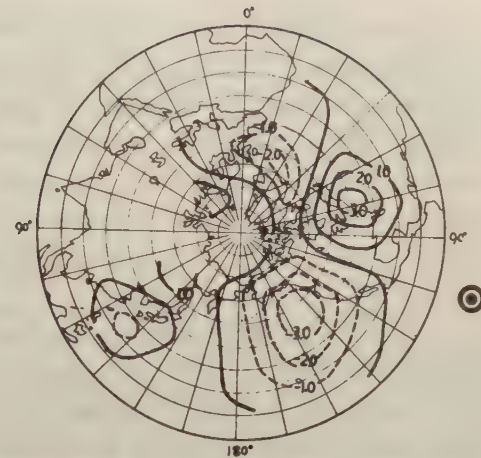

Fig. 4 Distribution of $f^{\circ}F2$ during the Main Phase of Magnetic Storm at 19h U.T. on October 28, 1951.

Fig. 5 Distribution of $f^{\circ}F2$ during the Last Phase of Magnetic Storm at 21h U.T. on October 28, 1951.

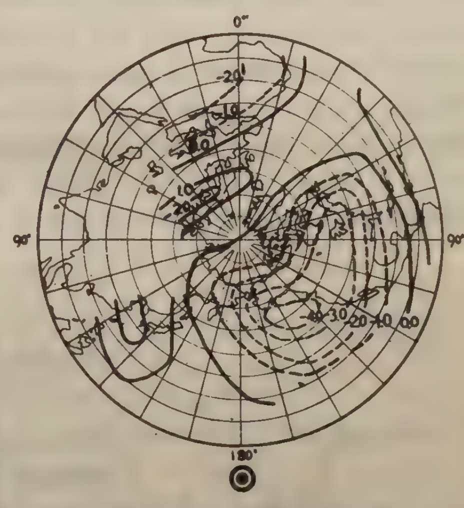

Fig. 6 Distribution of $f^{\circ}F2$ dnring the Last Phase of Magnetic Storm at 00h U.T. on October 29, 1951.

duration, it would not be difficult to find out the various effects on the ionosphere corresponding to each stage of the storm.

Using the data of about 40 ionospheric stations in the northern hemisphere, successive instantaneous changes of the world-wide distribution of F-2 layer disturbances are traced. In the following Figures 2 to 6, $\Delta f^{\circ}F2$, deviations of $f^{\circ}F2$ from the normal values, are drawn with contour lines of every one mc/s on the map viewed from above the north pole. With the oneset of the magnetic storm, a somewhat increased region of f°F2 appeared. Then, during the major part of this magnetic storm, this positive region of $\Delta f^{\circ}F2$ turned to negative and spread over the sunlit side near the auroral zone, while a positive anomaly appeared again at the western edge of the American Continent and grew rapidly extending to the southern edge of the auroral zone. These

... for several hours after the subsidence of magnetic activity with a succession of ...

... and patterns of dI/dt from 17h to 21h U.T. on October ...

... shown in Fig. 8.

An outstanding feature of this storm is the development of the remarkable ...

electric current stream near the southern edge of the auroral zone. As can be seen from the magnetogram at Agincourt (Fig. 9), the magnetic field has a sharp and intense ...

... A simple geometrical calculation is possible to ...

anomalous changes of the ionospheric disturbance during successive stages of the storm are illustrated in Figs. 2 to 4. The intense magnetic activity passed over rather suddenly at about 21h, U.T. and the gradual recovery phase followed. The remarkable positive region of $\Delta f^{\circ}F2$ diminished within a few hours after this, and then a large negative region developed in the sunlit-hemisphere. Figs. 5 and 6 show this large negative region during the last phase of the storm. This negative region remained active for several hours after the subsidence of magnetic activity with a dimention of over a few thousand kilometers.

In order to show these changes in more detail, variations of the geomagnetic H-component and $f^{\circ}F2$ of the ionosphere observed at several North American stations are reproduced in Fig. 7. Equivalent electric current-systems estimated from the geomagnetic disturbing forces and patterns of $\Delta f^{\circ}F2$ from 17h to 21h U.T., on October 28th, are shown in Fig. 8.

An outstanding feature of this storm is the development of the remarkable positive and negative anomalies in the $F2$ region which are closely related to a strong electric current-stream near the southern edge of the auroral zone. As can be seen from the magnetogram at Agincourt (Fig. 9), the magnetic field has a sharp and intense change between 19h and 20h, H increasing by about 800γ and Z decreasing by about 400γ. Taking into consideration the data obtained at Cheltenham and other stations, it can be shown that a very narrow but strong electrojct-stream was flowing near above the Agincourt observatory. A simple geometrical calculation is possible to

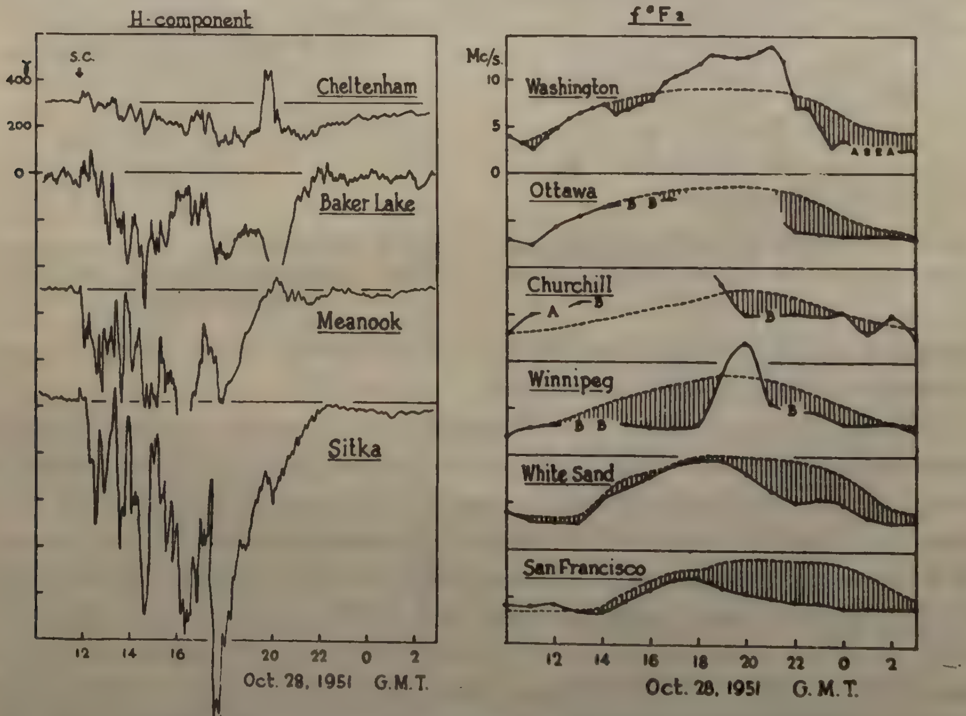

Fig. 7 Variations of geomagnetic H-component and $f^{\circ}F2$ of the the ionosphere.

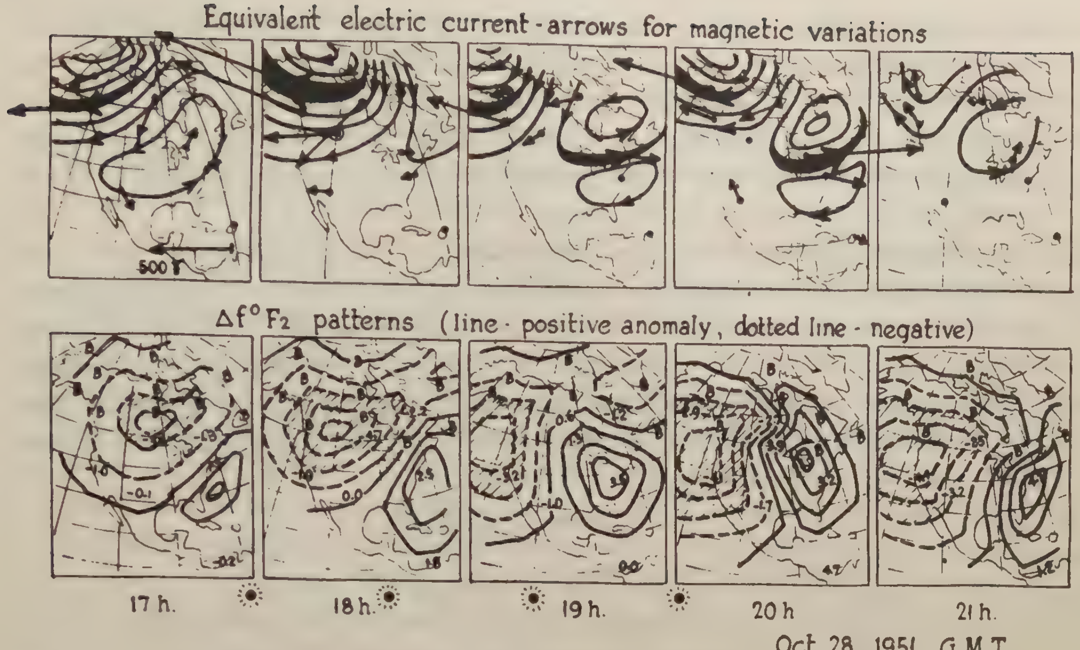

Fig. 8 Patterns of geomagnetic current-system and ionospheric $\Delta f^{\circ}F2$.

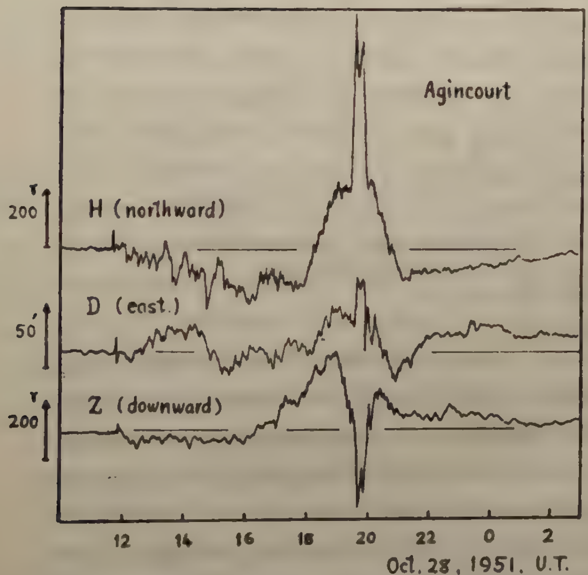

Fig. 9 Record of the magnetic storm of Oct. 28-29, 1951, at Agincourt, Toronto.

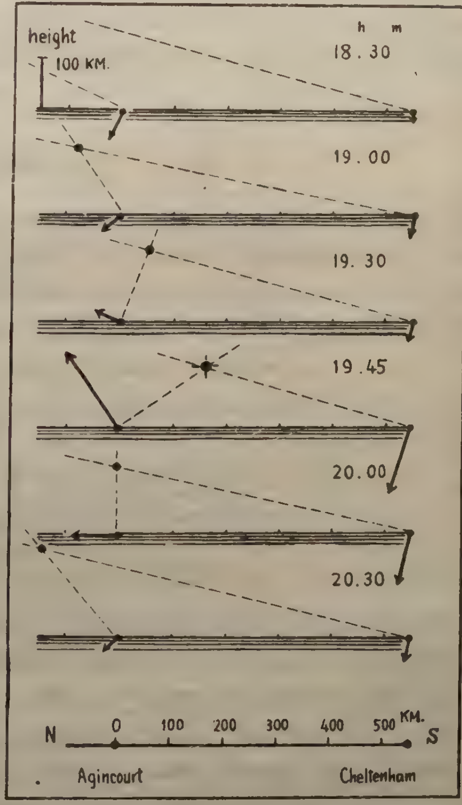

Fig. 10 Locations of an electrojet stream and geomagnetic disturbing forces (ΔH and ΔZ) at Agincourt and Cheltenham. 18h 30m to 20h30m U.T. on Oct. 28, 1951

determine the location of this electrojet, on the assumption that the external parts of H and Z components are 2/3 and 2 times the observed components, respectively. Fig. 10 shows the successive locations of the current centre; a sharp peak of the electrojet at 19h 45m was thus located at a height of about 100 km and about 150 km south from Agincourt. Assuming a single line current, the total current intensity, $I \sim H \cdot r/2$, is estimated at the order of 7×10^5 amperes.

Since this current-stream is very remarkable, it affords a good opportunity to examine its effect on the ionosphere. Actually, the electron-density of the *F*2-layer also showed an outstanding variation. A positive anomaly developed rapidly at the same time as the intense electrojet formation. This anomaly then disappeared and turned to the negative after the electrojet stream died out. Ionograms at several stations during this active period are reproduced in Fig. 11. Although most of the ionospheric records

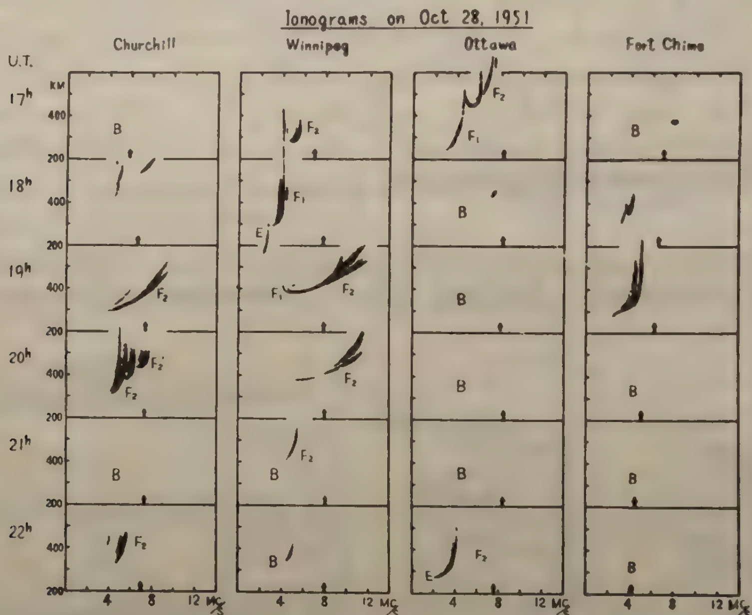

Fig. 11 Ionograms of 17h–22h, on 28th October, 1951, observed at four Canadian ionospheric stations. (Arrows indicate the values of $f°F2$ on quiet days.)

showed severe polar black-outs, fairly strong echoes from the *F* region were at times observed at Winnipeg and Churchill. Sudden appearance of a new layer of anomalously increased $f°F2$ and its disappearance are coincided with the formation of a strong electrojet stream during 19h to 20h; i.e. $h'F2$ was about 380 km and $f°F2$ increased more than 4 mc/sec. above the normal value at Winnipeg, while most of other records showed large upward shift or "blew up" of the *F*2 below the normal value.

One possible explanation of these ionospheric changes is simply that the positive anomaly is formed by the increase of ionization due to the penetration of the incomming corpuscular beam into the ionosphere. The ionization must be intense enough to

compete with dissipation processes which are supposed to become strong during the disturbance. This idea is also favourable for the explanation of the electrojet formation, because such a current-system is probably produced by an enhanced dynamo-action in the ionosphere due to the appearance of a highly conducting area. Howevere, this explains nothing about the negative anomaly in the $F2$-layer which is important in most cases of ionospheric storms.

As suggested by Martyn (1953), Maeda (1953) and Sato (1956), another explanation may be due to the effect of the vertical drift of electrons caused by the electric field postulated by magnetic storms. The vertical drift velocity is proportional to the current intensity, being upward when an eastward current is flowing (the northern hemisphere). In the present case, an intense eletrojet stream flows towards the east in the E region (about 100 km), and this will produce an upward drift if it is assumed that the impressed electric field is the same throughout the E and F regions. Since this result does not accord with the present observational fact in the $F2$ ionosphere, it is rather likely that there exist in the $F2$ region the currents which are returned from the eletrojet in the E region. Accordingly, the westward currents will produce a downward drift in the $F2$ region. Thus the observed ionospheric change of the sudden formation of a new layer in the lower $F2$ region may be explained qualitatively as the association of an intense electrojet stream. However, so far as this electron drift theory is concerned, it is almost impossible to account for such an enormous increase of electron density (more than 10^6 electrons per cm^3).

Conclusions

Discussions have been devoted to the two possible theories which could explain the close interrelation of ionospheric changes with the electrojet stream inferred from geomagnetic storm variations. In the present stage of investigations, however, there is no evidence that can exclude one of those possibilities, and it is more likely that both mechanisms may play some part in the entire process of storms.

Therefore, in order to construct a more consistent theory, a further study of this problem is desired with more of observational data and advanced knowledge of the dynamical behaviour of the ionosphere. It is the author's hope that the world-wide researches of the ionosphere during the Third International Geophysical Year, 1957–1958, will provide a vast amount of useful materials for further study and stimulate a new insight into this problem.

In concluding, the author wishes to express his thanks to Dr. T. Nagata and Dr. H. Uyeda for their kind advice and suggestions. A part of this research was carried out at the University of Toronto while the author was in Canada, and acknowledgments are extended to Dr. J.A. Jacobs for his encouragement throughout the study. The author's cordial thanks are also due to those who have kindly sent magnetic and ionospheric information, especially to Dr. J.H. Meek and Mr. O. Sandoz of Radio Physics Laboratory, Ottawa.

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[illegible] it is almost impossible to account for [illegible] (more than 10^6 electrons per cm^3).

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Meeting of the Society of Terrestrial Magnetism and Electricity:

The 24th General Meeting was held at the Nagoya University on October 24–26, 1958.

Number of the Reports read at the Meeting:

Night Airglow, 3; The Ionosphere, 18; Geomagnetism, 14; Cosmic Rays, 12; Rock Magnetism, 5; Atmospheric Electricity, 8.

Special presentation of paper; "Diurnaland Annual Variations of f_0F2 over the Polar Regions" by S. C. Coroniti and R. Penndorf (Research and Advanced Development Div., AVCO Mfg. Corp.)

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Vol. X No. 1

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CONTENTS

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